Recycling Biological Wastes: Biochar

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Abstract—*Soil is enriched by nutrients for supporting plant growth and development by adding some nutrient sources to it called fertilizers which can either be of natural or synthetic origin. Commonly used are the synthetic fertilizers which prove to be detrimental to soil health upon long term of use. Therefore, fertilizers of biological origin should be preferred for better management of nutrients added to soil. Although these biological fertilizers cannot sustain the soil health and quality for a very long period of time, this issue can be resolved by adding carbon to these fertilizers which sequesters atmospheric C to soil C as well as dissociates the ions bound in the soil that are unavailable to the plant. One such form of carbon that can be added is charcoal by integrating with added fertilizers for maintaining soil fertility. But simply using random charcoal would not be of much significance and thus the charcoal obtained from plant origin also known as biochar would be of better help in getting improved results of soil health and fertility status.*

Introduction

Human being the biggest threat to the environment possess a big loss to the soil and agricultural productivity and is also responsible for the rapidly changing climate all around the world which has various detrimental effects on both the natural flora and fauna which includes humans as well [1-2]. Though it is seen that agricultural productivity increased manifold to a very high level by use of agrochemical products [3]. The demand for these chemicals kept on increasing with time due to declining land area and rapidly increasing world's population. Using these inorganic fertilizers up to a certain limit is sustainable and do not harm the environment but with increasing human greed to increase the productivity to a very high level by increasing the dose of chemical fertilizers is very dangerous and is becoming a threat to the environment as well as humans [4]. Chemical fertilizers disturb the natural equilibrium of the soil sites and permanently damages them if used for a long time [5]. So now the need of the time clearly indicates that certain other organic fertilizers like biochar is to be used for maintaining the productivity along with the restoration of soil health which has positive impacts on both environment and agriculture.

Agriculture has to face three challenges at the same time which are ensuring food safety along with increasing income and productivity, adapting to climate change and also to mitigate the climate change. These challenges are exerting a heavy pressure on the natural resources supporting agriculture which is also to be released simultaneously with agricultural production by introducing several variations in the production system. Various other problems which moves parallel with the ongoing agricultural production are agricultural waste management, soil quality degradation, and adverse effects on climate. These issues can be resolved to a large extent by use of biochar [18-19].

Biochar is a fine-grained, carbon-rich, porous product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperatures (~350–600°C) in an environment with little or no oxygen [27]. Biochar is not a pure carbon, but rather mix of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), Sulphur (S) and ash in different proportions [28] [12]. Biochar is charcoal that has been produced under conditions that optimize certain characteristics deemed useful in agriculture, such as high surface area per unit of volume and low amounts of residual resins [17].

In the recent years biochar application to the croplands has started to maintain and improve the quality of soil and crop. As a soil amendment, biochar helps to improve the Earth's soil resource by increasing productivity and crop yields, reducing soil acidity, reducing the need for some chemical and fertilizer inputs and potentially providing other soil benefits [6-7]. Biochar has the ability to improve soil fertility, leading to higher crop yields. Biochar has the potential to increase the world's agricultural productivity by improving degraded soils. Because of biochar's ability to enhance the availability of plant nutrients, soil nutrient retention is improved. This means that less fertilizer needs to be applied which reduces the cost of producing the crop [8].

A study revealed that biochar can significantly reduce both N and P fertilizer loss [9]. The biochar treatments were found to increase the final biomass, root biomass, plant height and number of leaves in all the cropping cycles in comparison to no biochar treatments [10]. Biochar improved the uptake efficiency of nutrients by plants, Total biomass production was increased by the application of biochar [11].

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PRODUCTION OF BIOCHAR

In the partial or total absence of oxygen the thermal decomposition of plant derived biomass (pyrolysis) can be manipulated to yield, a solid carbon-rich residue generically referred to as char. As distinct from char biochar comprise biomass-derived char intended specifically for application to soil, that is, according to its purpose. As such, it extends to related materials produced under more and less controlled conditions with and without total exclusion of oxygen, such as conventional charcoal. Biochar is produced by heating biomass in the total or partial absence of oxygen. Pyrolysis is the most common technology employed to produce biochar, and also occurs in the early stages of the combustion and gasification processes. Pyrolysis systems employed for biochar production can be categorized into three types: (1) slow pyrolysis, (2) fast pyrolysis, (3) gasification. Besides biochar, bio-oil and gas can be collected from modern pyrolysers. These could be refined to a range of chemicals and/or used as sources of renewable energy if derived from sustainably produced biomass.

Mode	Heating Rate	Temp °C	Residence Time	Material Size (Diameter)	Main Products
Slow Pyrolysis	Slow .1-20 °C/m	400 -650	Minutes to days	1 - 200 mm	Oil, gas, char ~1/3 each
Fast Pyrolysis	Very Fast > 300 °C/s	700	second	<1 mm	Bio-oil, 75% Char, 10-20%
Gasification	2-100°C/m	> 800	5-30 mins	5-20 mm	Gas, 80% Char, 10-20%

SOIL RECONSTRUCTION

Production of biological life affects the land it utilizes mostly in a negative way by exhausting all its biomass. Thus, this heavy utilization of biomass exhausts the land and deteoriate the soil extensively, lowers their fertility levels, destroys the habitation site of many organisms, and adds to the task of polluting the soil as well. Major concluding problem of the above listed is the loss of soil carbon which can be recovered by the addition of biochar as a highly effective amendment to the soil. Thus, biochar can be said to be the fertility restorer of the soil.

Biochar and compost applied alone or in combination significantly increased soil pH, total organic carbon, available phosphorus, mineral nitrogen, reduced exchangeable acidity, and increased effective cation exchange capacity of soil [14]. The increase in soil organic matter and CEC was quite huge as carbon and exchangeable cations were introduced by biochar application [15]. Actually, besides the direct amendment of biochar on soil's properties, biochar can also alter microbial and nutritional status of the soil within the plant rooting zone through changing soil physical properties (e.g., bulk density, porosity, and particle size distribution). Overall, the improvement of soil properties is highly contributed to the increased of both nutrient and water use efficiency and crop productivity. Various positive effects on adding biochar to soil as amendment includes higher capacity of the soil to store water, aeration of the soil and the release of nutrients through raising the soil's pH-value. Biochar serves as a carrier for plant nutrients and mixing biochar with such organic waste as wool, molasses, ash, slurry and pomace produce organic carbon-based fertilizers which prevent the leaching of nutrients, a negative aspect of conventional fertilizers. These nutrients are available as and when the plants need them [21]. Schnell et al. (2012) found that topdressed sorghum-derived biochar @ 3Mg per hectare (with no incorporation) on an eastern Texas Alfisol caused significant surface runoff P losses compared with control soils and that incorporating the biochar into soil reduced runoff P losses by 78% [23]. Addition of 0.5% BC to the surface soil layer retarded the vertical movement of NH_4^+-N into the deeper layers within the 70-day observation time, especially during the first 7 days at 10-cm depth and the later experimental period at 20- cm depth [29]. By earlier demonstration it is being studied that the highly aromatic nature, high surface area, micropore volume, and the presence of abundance of polar functional groups in biochar, the material has been found to be effective in the uptake of a variety of organic chemicals including pesticides, emerging contaminants such as steroid hormones [30]. Growth indices of wheat seedlings under these treatment conditions were compared and it was concluded that biochar had the most significant effect on wheat seedlings in the mixed heavy metals solution. At the same time, biochar can effectively reduce the toxicity of heavy metals in the germination of wheat seed. This can provide a preliminary basis for the remediation of soil contaminated with heavy metals. Effects of different concentrations of biochar has been positively seen on germination potential, germination rate, germination index and vitality index of wheat seeds under heavy metal treatments [37].

Increase in Crop Productivity

Crop productivity depends largely on the quality of the soil, since use of biochar greatly enhances the soil fertility status thereby upgrading soil fertility to a higher level. Difference in yields of crops with and without use of biochar has been significantly seen. A study revealed that the seasonal yield increase due to biochar application was in average around 1.2 Mg ha^{-1} for maize and 0.4 Mg for soybean, independently of fertilization, over seasons and sites [16]. Soil amendment with BC is expected to increase crop productivity by enhancing the supply of nutrients and by fostering the activity of soil microorganisms responsible for mobilizing soil nutrients and making them more available to crops [33-36] and promoting root expansion. In application of 0, 8 and 20 t ha^{-1} of biochar to a Colombian savanna Oxisol for 4 years (2003–2006), under a maize-soybean rotation, maize grain yield did not significantly increase in the first year, but increases in the 20 t ha^{-1} plots over the control were 28, 30 and 140% for 2004, 2005 and 2006, respectively. The availability of nutrients such as Ca and Mg was greater with biochar, and crop tissue analyses showed that Ca and Mg were limiting in this system. Soil pH increased, and exchangeable acidity showed a decreasing trend with biochar application. We attribute the greater crop yield and nutrient uptake primarily to the 77–320% greater available Ca and Mg in soil where biochar was applied [20]. Kammann et al. (2012) added peanut (Arachis hypogaea L.) hull biochar at 50 Mg ha^{-1} to a German Luvisol and then grew ryegrass (Lolium perenne L.). The authors observed a significant increase in biomass yield when compared to controls. Th e cause of the increase in yield was unknown, but it could have been a function of reduced N loss to denitrification and hence greater N uptake by plants grown in the presence of biochar [22]. In sole application, biochar obtained by pyrolysis of Cymbopogon winterianus Jowitt (Poaceae) chaff at 450 °C for 60 min @ 4.0 t ha^{-1} displayed 17% higher biomass yield as compared with control [13]. Biochar has been shown to promote plant productivity and yield though several mechanisms. Physical conditions change with biochar; its dark color alters thermal dynamics and facilitates rapid germination, allowing more time for growth compared with controls [24].

Environmental Protection

In atmosphere CO_2 emissions are increasing at a very high rate and the trajectory followed by this increase is leading us towards rapidly changing climate which is detrimental to flora and fauna on the planet and is almost irreversible to recover. So to mitigate this huge problem various measures has been adopted and biochar is one of them. Organic-carbon storage in tropical soils, especially when in combination with phosphorus supply (for instance through locally available rock phosphates) would serve two purposes: the quality of tropical soils and their productive capacity for a strongly growing population would improve, and at the same time the current rise in atmospheric CO_2 levels would be attenuated to such an extent that adverse effects of human-induced global climatic change, such as sea-level rise and intensification of local climate variability, may be kept down to manageable proportions [25]. According to the study by Lehmann et al, high OC concentrations were found in all BC containing soils compared to adjacent soils. The OC concentrations of BC-containing soils ranged from 66 to 518 g/kg in the surface and from 53 to 572 g/kg in the subsurface. For the adjacent soils, OC concentrations ranged from 9 to 149 g/kg in the surface and from 8 to 94 g/kg in the subsurface. Average OC concentrations of the BC-containing soils were 5.7 and 12.3 times higher than the adjacent soils for surface and subsurface, respectively [26]. With high sorption capability to organic pollutants in soils and resistance to degradation, biochars can pre-concentrate pollutants in contaminated soil then feed to the immobilized microbial decomposers [31]. Conversion of straw to biochar reduce CH4 emission and retain more carbon in paddy soil, and also stimulate soil microbes, enhance soil productivity and increase grain yields. Thus, converting straw to biochar is a desired approach that has advantages of improving soil productivity sustainability and mitigating CH4 emission [32]. Biochar can reduce rice paddy soil N_2O emissions (i.e. Anthrosols) by almost 40%; this may significantly mitigate climate change, as ~140 Mha are used as paddy fields globally [38]. Agricultural land use requires replacement of nutrients by fertilization and can mitigate climate change by sequestering C in soils. Biochar is thought to sequester C in soils and stabilize non-charred soil organic C, which may have an impact on nitrification and subsequently on N_2O emissions [39].

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